Algae on Mars: A Summary of the Evidence

K. Latif[1*], J.G. Ray[2] and O. Planchon[3]

[1]National Centre of Excellence in Geology, University of Peshawar, Khyber Pakhtunkhwa, Pakistan

[2]School of Biosciences, Mahatma Gandhi University, Kerala, India

[3]National Center for Scientific Research, Biogéosciences, University of Bourgogne, France

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Abstract

Evidence from Mars of what may be algae, thrombolites, microbialites, microbial mats, stromatolites, and ooids is summarized. Also briefly discussed is evidence of chlorophyll, seasonal fluctuations in atmospheric oxygen, and what may be photosynthesis-oxygen gas vents adjacent to specimens resembling algae and lichens. The possible presence of calcium carbonate and calcium oxalate is also summarized the latter of which might be produced by lichens: an algae-fungi symbiotic organism that Joseph et al. (2021) believe are attached to rocks on Mars.

Key Words: Mars, algae, cyanobacteria, thrombolites, microbialites, microbial mats, stromatolites, ooids.

*khalidlatif@uop.edu.pk

1. Algae & Cyanobacteria on Mars

Organisms that have been classified as algae include unicellular microalgae, diatoms, cyanobacteria, and multicellular algae that range from relatively small to giant kelp and seaweeds (Graham et al. 2016). Specimens resembling algae and cyanobacteria have been observed on the surface of Mars (Joseph et al. 2020a; Kaźmierczak 2016, 2020; Krupa 2017) and within the interior of meteors (reviewed in Hoover 2011; Rozanov et al. 2020) the latter of which may have delivered life to Earth and Mars (Joseph 2009; Joseph et al. 2019, 2020b).

Classifications change and not all investigators agree, but not all algae are cyanobacteria the latter of which have been identified as "blue green algae" which is a prokaryote that reproduces asexually by cell division, whereas green and most other types of algae are eukaryotes (Graham et al. 2016). However, eukaryotic and prokaryotic algae (cyanobacteria) contain chloroplasts, a circular packet of DNA, and both are photosynthetic and produce oxygen and secrete what becomes calcium. Calcium binds sedimentary grains that build up and form clusters and clots (thrombolites) and that may become microbial mats and stromatolites that are layered and laminated and/or microbialites may be clotted or layered—all of which are believed to be constructed primarily by archaea and cyanobacteria. For the purposes of this summary, we will not distinguish between prokaryotic and eukaryotic algae.

2. Algae, Thrombolites, Microbialites, Mats & Stromatolites on Mars

Sedimentary structures photographed on Mars have been identified as resembling thrombolites and microbialites as based on microanalysis and structural parallels with similar formations on Earth (Bianciardi et al. 2014, 2015; Noffke, 2015; Rizzo, & Cantasano 2009, 2016; Ruff & Farmer 2016). Microbial mats (Joseph 2014; Joseph et al. 2019; Rabb, 2018; Small 2015) and larger structures nearly identical to the concentric domical stromatolites of Lake Thetis, Australia, have also been observed in the ancient lake beds of Gale Crater (Joseph et al. 2020b,c). This is notable not only because of their larger size but as the lakes of Western Australia are believed to be analogs for the ancient lakes of Mars and press reports suggest NASA has accepted this analog and the Mars rover perseverance may search for additional Lake- Thetis-like domical stromatolites (NASA 2021); the discovery of which will confirm previous reports of concentric stromatolites on Mars (Joseph et al. 2020c).

Calcium and calcium carbonate are precipitated in the mucous of cyanobacteria/algae via photosynthetic CO^2or HCO^3 (Graham et al. 2016). Thrombolites, microbialites, microbial mats, and stromatolites are comprised of sediments that have been “cemented” together by secretions that form calcium carbonate (Graham et al. 2014). Analysis of spectra and orbital and ground based investigations, have provided evidence of calcium carbonate on the surface of Mars (Boynton et al. 2009; Krall et al. 2014; Sutter et al. 2012; Wray et al. 2016), and is an obvious biosignature. Residue, encrustations, and veins of white-colored substances have also been interpreted as indicative of calcium carbonate (Joseph et al. 2020a, 2021) and calcium oxalate (Joseph 2021) and the association between what resembles algae, lichens, fungi, hyphae, encrusted mycelium and microbial mats noted. Fossilized impressions of algae (Kaźmierczak 2016, 2020) and ooids (Lin 2016; Joseph et al. 2020a) have also been observed on Mars, the latter of which, on Earth, is also formed via calcium secretions.

Flowing filamentous tangles have also been observed on Mars attached to sediment and the sides of rocks and that resemble filamentous algae *Klebsormidium* and *Oedogoniun* (Joseph et al. 2020a). These seaweed-like tangles were photographed in the ancient lake beds of Gale Crater.

3. Algae, Oxygen & Photosynthesis on Mars

Algae produce oxygen by photosynthesis, made possible via biological pigments, most notably chlorophyll. Evidence interpreted as representing chlorophyll has also been reported as based on analysis of data collected by the rover Curiosity in Gale Crater (Stromberg et al. 2014, 2019). What appear to be gas-vent apertures for the release of oxygen secondary to photosynthesis have also been photographed

Gale Crater, within microbial mats and moist substrates that appear to be colonized by algae and lichens (Joseph et al. 2020z). Martian atmospheric oxygen is continually replenished despite a 5 year half-life and leakage into space and levels increase in springer and summer (Trainer et al. 2019) and which can be explained by the presence of photosynthesizing lichens and algae as these fluctuations parallel seasonal fluctuations in biologically produced oxygen on Earth (Joseph et al. 2020d,e).

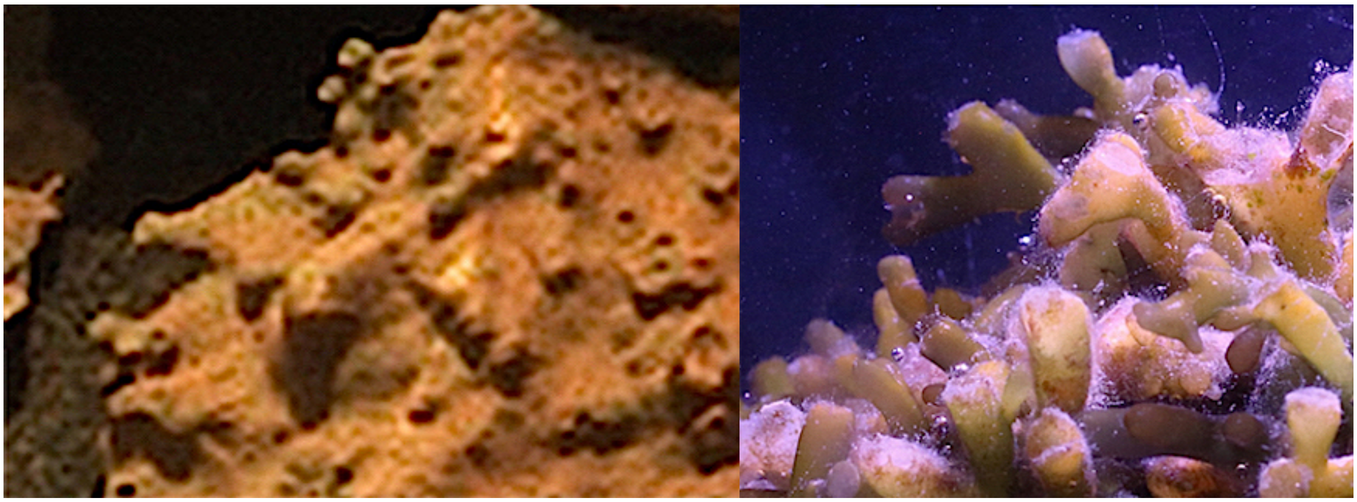

Figure 1: (Left, from Joseph et al. 2020d) Sol 232: Gas-vent apertures for the release of oxygen secondary to photosynthesis within microbial mats? Photographed in Gale Crater. (Right) Cone- like tubes for the venting of oxygen produced by photosynthesizing algae (reproduced from Freeman et al. 2018).

To summarize: there is evidence of fossilized thrombolites, microbialites, microbial mats, stromatolites, algae and ooids. Chlorophyll, seasonal fluctuations and increases in atmospheric oxygen, specimens resembling oxygen-gas vents adjacent to what appears to be algae and lichens have been reported. What may be calcium carbonate and calcium oxalate has been observed the latter of which, on Earth, is produced by lichens an algae fungi symbiotic organism that may have been identified on Mars (Joseph 2021; Joseph et al. 2020a, e, 2021).

4. Living Algae & Cyanobacteria on Mars

Levin, Straat and Benton (1978) observed what appeared to be green patches on Mars rocks that had been photographed during the 1976 Viking mission. A comparison of sequential photos indicated that the green patches changed in size and appear to have expanded. Levin et al (1978) raised the possibility these may be algae but also admitted it could be green colored sediment (see also Levin & Straat 2016).

Figure 2: Gale Crater. Features resembling microbial mats, tubular organisms and exfoliation processes possibly due to the endolithic growth of unicellular cyanobacterium. These green patterns are similar to those observed by Büdel and colleagues in South Africa and Antarctica (Büdel et al. 2004, 2008). Chrooccocidiopsis and other species of algae including Saphophyte cyanobacteria also display patterns of changing color patterns particularly in response to insufficient water. Cyanobacteria or blue-green algae contain chlorophyll and phycobiliproteins, the latter comprising pigments ranging from the blue phycocyanin to the red phycoerythrin. The early-diverging, rock-dwelling cyanobacterium genus Gloeobacter is often colored purple (Graham et al. 2016). In high irradiance environments, cyanobacteria also produce carotenoids (yellow to orange pigments) that provide protection against irradiance (Pattanaiki et al. 2007).

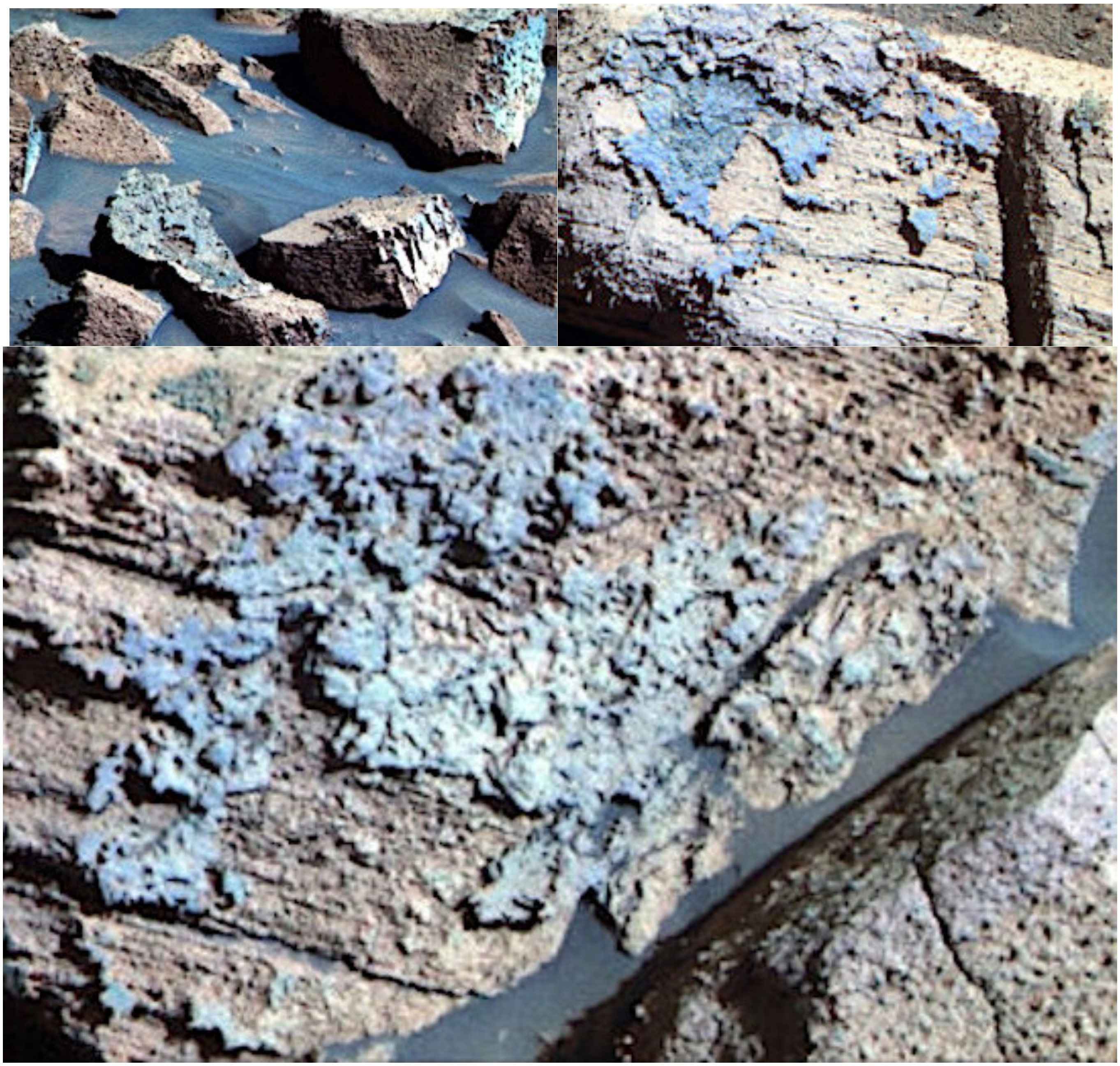

Figure 3: Gale Crater. Specimens resembling microbial mats constructed by cyanobacteria.

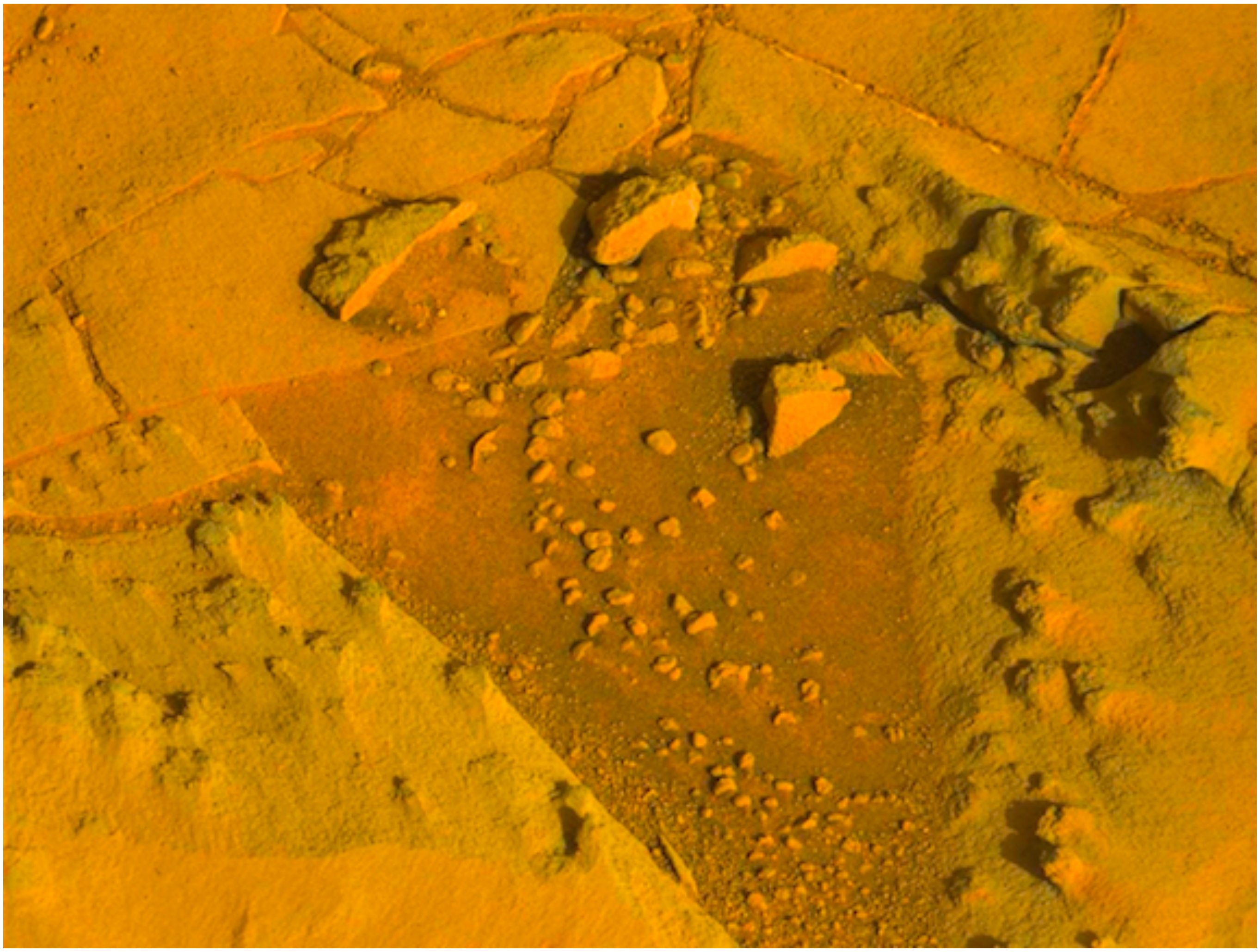

Figure 4. Gale Crater: Green sphericals upon Martian sand, soil, rocks and pinnicle-columnar structures resembling terrestrial stromatolites and thrombolites (see Graham et al. 2014) and algae growing in shallow water (see Ray and Thomas 2012). On Earth, the greenish-coloration of sand and rock is due to green cryptoendolithic cyanobacteria (Büdel et al. 2004, 2008; Jung et al. 2019; The darkening in soil coloration may indicate moisture. Thin sheets of sphericals covering Martian sand, rock and stromatolite-like structures/protrusions, similar to the layered structures of terrestrial stromatolites and thrombolites resemble fossilized as well as living stromatolites and thrombolites on Earth (Graham et al. 2014). These sheets are also similar to algae growing in shallow water, but may be frozen – the arrangement of sandy substance in between rocks is the typical nature of shallow rocky pools (Ray & Thomas 2012; Ray et al. 2009).

Figure 5. Algae-like spherules and open cone-like protrusions similar to fossilized gas bubbles (upper left) on broken rocks photographed in the Gale Crater. These specimens are similar to those subjected to stressed conditions (Gaysina et al. 2019) and appear to have been recently moistened. Terrestrial algae similar to these specimens may assume these features when subjected to highly stressful conditions (Gaysina et al. 2019).

Figure 6. Gale Crater: Algae and stromatolite pinnacles. The greenish-coloration may be due to green cryptoendolithic cyanobacteria (see (Büdel et al. 2004, 2008; Jung et al. 2019). The darkening in soil coloration may indicate moisture. Thin layer of green-colored substances on layered formations photographed in the Gale Crater. The overall appearance is similar to sand strata layers with fluvial water pathways. The contrasts between upper vs lower soils indicates the presence of moisture. Speculation: these strata may be harboring epipelic cyanobacteria, and algae recently exposed to water (see Ray et al. 2009). The possibility these are hydrated minerals is not likely due to the locations and insufficient quantities of minerals so far detected vs the widespread and somewhat homogenous distribution of the specimens depicted here. Surface weathering of sandstone, such as occurs in some arid and desert environments, also support a biological interpretation, as colonies of green cryptoendolithic cyanobacteria are typically found in association (Büdel et al. 2004). Enhanced with HDR processing.

As reported at the Lunar and Planetary Society (Krupa 2017), the Spirit Rover's Pan Cam photographed water pathways surrounded by a “thin layer of green material" and "green spherules" that resembled algae in the soil. Krupa (2017) hypothesized these may be photosynthetic organisms “and their green color suggests that the spherules contain a photosynthetic compound similar to green chlorophyll.”

Subsequently, a team that included ten established experts in algae or algae-fungi symbiotes observed Martian specimens that resembled algae at ground level, atop and alongside rocks, mudstone and sand and that were photographed in association with or adjacent to specimens similar to ooids, lichens, fungi, microbial mats, and stromatolites (Joseph et al., 2020a,c). “These algae-like specimens, depending on substrate, appear as green clumps, spherules, cake-like layers, thin sheet-like layers and thick layered leafy vegetative masses of material which partially cover Martian rocks, sand, and fungi-like surface features. Many specimens appeared to be moist or covered by a thin layer of ice” (Joseph et al. 2020a). The authors acknowledged the exact identity of these specimens is unknown, but if biotic, they may include blue-green algae (cyanobacteria) and green algae. Also observed the lake beds of Gale Crater (Joseph et al. 2020a): Greenish and yellow substances covering Martian sand and rock and specimens that resemble microbial mats; all of which were enmeshed in a carpet of yellow-green substances within which are embedded patterns similar to those constructed by stromatolite- and mat-making filamentous cyanobacteria during the Cambrian era on Earth (Latif et al. 2019).

5. Conclusions

The evidence summarized in this report supports the hypothesis that mat- and stromatolites-building algae and cyanobacteria colonized Mars early in the history of that planet, and the hypothesis that algae continue to thrive and may contribute to oxygen production on Mars.

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